

## Influence of essential oils of plants on the migration activity of *Tribolium confusum* (Coleoptera, Tenebrionidae)

V. O. Martynov, O. G. Titov, T. M. Kolombar, V. V. Brygadyrenko

Oles Honchar Dnipro National University, Dnipro, Ukraine

### Article info

Received 04.04.2019  
Received in revised form  
03.05.2019  
Accepted 06.05.2019

Oles Honchar Dnipro National  
University, Gagarin ave., 72,  
Dnipro, 49010, Ukraine.  
Tel.: +38-050-93-90-788.  
E-mail: brigad@ua.fm

**Martynov, V. O., Titov, O. G., Kolombar, T. M., & Brygadyrenko, V. V. (2019). Influence of essential oils of plants on the migration activity of *Tribolium confusum* (Coleoptera, Tenebrionidae). *Biosystems Diversity*, 27(2), 177–185. doi:10.15421/011924**

Pest control should be ecologically-based, therefore use of ecologically safe approaches is the best variant. Essential oils of plants can affect the main metabolic, biochemical, physiological and behavioural functions of insects. In the experiment, we evaluated the influence of 20 essential oils on migration activity of imagoes of *Tribolium confusum* Jacquelin du Val, 1863 in the conditions of a laboratory experiment. Notable repellent activity against *T. confusum* was exhibited by essential oils of *Jasminum officinale* and *Thuja occidentalis*. Essential oils of *Zingiber officinale* and *Cedrus atlantica* had an attractant effect on imagoes of *T. confusum*. Essential oils of *Rosmarinus officinalis*, *Melaleuca alternifolia*, *Lavandula angustifolia* and *Cinnamomum verum* exhibited repellent properties while essential oils of *Juniperus communis* and *Citrus sinensis* had an attractant effect on the pests. Therefore, out of 20 studied essential oils, only four samples had notable biological effect on migration activity of *T. confusum* imagoes. These data indicate the possibility of using essential oils or their main components as ecologically safe natural repellents against pests of stored wheat and products of its processing.

**Keywords:** pest control; biopesticides; plant protection; repellent; attractant.

### Introduction

Taking measures against pests should be ecologically-based (EBIPM) and be undertaken in the context of integrated management of agricultural crops and complex control of pests, which means that use of ecologically safe methods is the best variant (Koul & Walia, 2009). Over the past 50 years, pest control in the agriculture has been based on using synthetic chemical insecticides in field agroecosystems and in conditions of greenhouse cultivation.

However, synthetic insecticides are toxic, they have unfavourable effects on the environment, polluting soil, water and air, and also when broadly used provoke development of resistance of target species and significant damage to populations of non-target species of invertebrates (Benhalima et al., 2004; Pimentel et al., 2009; Brygadyrenko & Ivanyshyn, 2015; Martynov & Brygadyrenko, 2017, 2018; Shulman et al., 2017). Furthermore, synthetic insecticides negatively affect human health; strict ecological regulation of using pesticides has led to increase in the number of studies on use of natural plant extracts as alternative synthetic preparations (Isman, 2004; Pérez et al., 2010).

There are 17,500 species of aromatic plants and around 300 essential oils that are commercially valuable for cosmetics, the pharmaceutical and food industries (Bakkali et al., 2008; Pushpanathan et al., 2008; Ebadollahi et al., 2015). Over 2,000 species of plants have insecticide activity (Klocke, 1989). Many commercial essential oils are included in the Generally Recognized as Safe List, which is fully recognized by Environmental Protection Agency and Food and Drug Administration in the USA (Burt, 2004).

Essential oils are secondary metabolites and are present in all parts of plants. They are complex compounds which contain many components which determine the properties of the essential oils. Among the components, there are terpenes, aromatic and aliphatic compounds. The main terpenes are monoterpenes and sesquiterpenes (Bakkali et al., 2008; Koul et al., 2008). Monoterpenes make up to 90% of essential oils and are represented by compounds different in structure: acyclic

(geraniol) and cyclic (terpineol) spirits, phenols (thymol), ketones (thujone), aldehydes (citronellal), acids (chrysanthemic acid) and oxides (1,8-cineole). Aromatic compounds, such as cinnamaldehyde, chavicol, anethole, safrole and apiole, are derivatives of phenylpropane and are present in lower content (Isman, 2006; Tripathi et al., 2009).

Essential oils affect the main metabolic, biochemical, physiological and behavioural functions of insects (Mann & Kaufman, 2012), and can also block respiratory tracts and lead to asphyxiation and death of pests (Kaufmann & Briegel, 2004; Rotimi et al., 2011). They can have toxic, fumigative, repellent, antifeedant, ovicidal, attractant and other effects (Werdin-Gonzalez et al., 2008). A number of scientists (Isman, 2000; Gutierrez et al., 2009) have reported neurotoxic, cytotoxic, phototoxic and mutagenic activity of essential oils on insects.

Botanical insecticides have a number of advantages: they do not persist in the environment, pose relatively low risk for non-target organisms (useful predators and parasites) and are relatively non-toxic for mammals (Weinzierl, 1998; Scott et al., 2003). They usually quickly decompose in the environment and are easily digested by the animals, which receive sub-lethal doses (Grđiša & Grđić, 2013).

Reasons for the limited commercial development of botanical insecticides are their relatively slow impact, variable efficiency, absence of stability and non-constant availability (Isman, 2008) compared to synthetic analogues. Other obstacles for commercializing botanical insecticides are deficiency of natural resources, difficulties of standardisation, control of quality and registration (Isman, 1997).

*Tribolium confusum* Jacquelin du Val, 1863 is one of the commonest insect pests of storages, damage from which is 5–30% of global agricultural production. The reasons for broad distribution of *T. confusum* are the morphological, physiological and behavioural features of the insect, and also the favourable conditions created for it by humans (Hana & Mohammed, 2013).

The objective of this article was to evaluate the impact of different essential oils on the migration activity of *T. confusum* in the conditions of a laboratory experiment.

## Materials and methods

In the experiment, we used imagoes of *T. confusum*. Before the experiment, the animals were kept in a common container with wheat flour. The beetles were selected randomly. The experiment included three stages. At the first stage, we planned to determine the essential oils which can frighten off or attract imagoes of *T. confusum* more efficiently than others. In the container (50 x 33 x 19 cm), we put wheat flour of higher sort (400 g) in a layer of 1 cm thickness. Then, in the container, we placed 44 plastic cups with the bottoms removed (0.1 L capacity) at a distance of 0.5 cm one from another with 80 g of flour and 30 imagoes of *T. confusum* in each one. In 40 cups, in flour on depth of 3 cm, we put a cotton pad of 0.4 cm diameter, saturated with 0.06 mL of essential oil (0.48 mL/cm<sup>2</sup>). In one experiment, for each of 20 types of essential oil (Table 1), we used two cups. The other four cups were used as control (in them, we put cotton pads of 0.4 cm diameter without processing with any essential oil).

**Table 1**

Essential oils used in the experiment for determining migration activity of *T. confusum*

Sub-stance	Plant	Chemical composition		ISO	References
		compounds	concentration, %		
Jasmine oil	<i>Jasminum officinale</i> Linnaeus, 1753	linalool	6.4	–	Wei & Shibamoto, 2007
		benzyl acetate	22.9		
		benzyl alcohol	6.5		
		<i>cis</i> -jasmone	2.9		
		<i>p</i> -cresol	1.4		
		<i>cis</i> -3-hexenyl benzoate	1.1		
		eugenol	3.0		
		methyl palmitate	1.2		
		isophytol	7.5		
		<i>cis</i> -phytol	15.0		
Grape-fruit oil	<i>Citrus paradisi</i> Macfadyn, 1830	$\alpha$ -pinene	0.4	3053	Uysal et al., 2011
		sabinene	0.3		
		$\beta$ -pinene	0.8		
		$\beta$ -myrcene	0.7		
		$\alpha$ -terpinene	0.7		
		limonene	91.5		
		linalool	1.1		
		<i>trans</i> -limonene oxide	0.9		
		citronellal	0.4		
		$\alpha$ -terpineol	0.3		
		nerol	0.3		
		neral	0.4		
		geraniol	0.3		
		geranial	0.4		
Eucalyptus oil	<i>Eucalyptus globulus</i> Labillardière, 1861	$\alpha$ -pinene	5.65	770	Abdossi et al., 2015
		$\beta$ -pinene	0.31		
		sabinene	0.65		
		limonene	0.84		
		1,8-cineole	76.65		
		$\gamma$ -terpinene	0.63		
		terpinen-4-ol	0.37		
		$\alpha$ -terpineol	1.96		
		$\alpha$ -terpineol acetate	4.85		
		isolekene	0.54		
		$\alpha$ -gurjunene	0.85		
		$\beta$ -gurjunene	0.36		
		alloaromadendrene	3.98		
		aromadendrene	0.51		
Rosemary oil	<i>Rosmarinus officinalis</i> Linnaeus, 1753	$\alpha$ -pinene	14.90	1342	Gachkar et al., 2007
		camphene	3.33		
		$\beta$ -octanone	1.61		
		myrcene	2.07		
		1,8-cineole	7.43		
		linalool	14.90		
		camphor	4.97		
		borneol	3.68		
		terpinen-4-ol	1.70		
		verbenone	1.94		
		piperitone	23.70		
		bornyl acetate	3.08		
		$\beta$ -caryophyllene	2.68		

Sub-stance	Plant	Chemical composition		ISO	References
		compounds	concentration, %		
Cinnamon oil	<i>Cinnamomum verum</i> J. Presl, 1825	<i>cis</i> - $\beta$ -farnesene	1.26		Jayaprakash et al., 2002
		$\alpha$ -bisabolol	1.01		
		heptanal	1.09		
		nonanal	1.09		
		$\alpha$ -copaene	23.05		
		$\alpha$ -bergamotene	27.38		
		<i>trans</i> -cinnamyl acetate	2.41		
		aromadendrene	1.79		
		$\alpha$ -humulene	6.19		
		germacrene D	2.10		
		viridiflorene	3.29		
		$\alpha$ -muurolene	2.70		
		$\gamma$ -cadinene	1.57		
		$\delta$ -cadinene	5.97		
		ledol	1.29		
		spathulenol	2.02		
		globulol	1.67		
		$\beta$ -bisabolol	1.26		
Spruce oil	<i>Picea abies</i> (Linnaeus) H. Karsten., 1881	tantene	2.27	–	Radulescu et al., 2011
		$\alpha$ -pinene	5.40		
		camphene	7.55		
		limonene	9.29		
		borneol	1.11		
		bornyl acetate	11.78		
		$\alpha$ -muurolene	1.61		
		$\gamma$ -cadinene	1.54		
		$\delta$ -cadinene	9.49		
		nerolidol	1.01		
		$\alpha$ -muurolol	11.01		
		$\delta$ -cadinol	1.48		
		$\alpha$ -cadinol	21.39		
		manool	3.58		
Thuja oil	<i>Thuja occidentalis</i> Linnaeus, 1753	$\alpha$ -thujene	1.46	–	Jirovetz et al., 2006
		$\alpha$ -pinene	3.33		
		camphene	2.55		
		$\alpha$ -fenchene	2.04		
		sabinene	12.14		
		$\beta$ -pinene	1.14		
		myrcene	4.05		
		<i>p</i> -cymene	2.37		
		$\alpha$ -terpinene	1.83		
		limonene	2.36		
		$\beta$ -phellandrene	1.65		
		$\gamma$ -terpinene	2.29		
		<i>trans</i> -sabinene hydrate	1.09		
		terpinolene	2.32		
		fenchone	12.87		
		linalool	1.89		
		$\alpha$ -thujone	2.76		
		$\beta$ -thujone	9.48		
Sandalwood oil	<i>Pterocarpus santalinus</i> Linnaeus, 1782	camphor	1.24		Subasinghe et al., 2013
		terpinen-4-ol	3.32		
		linalyl acetate	1.24		
		sabinyl acetate	16.55		
		terpinyl acetate	1.17		
		$\beta$ -caryophyllene	1.23		
		$\delta$ -cadinene	1.29		
Ginger oil	<i>Zingiber officinale</i> Roscoe, 1807	<i>cis</i> - $\alpha$ -santalol	31.67	3518	Singh et al., 2008
		epi- $\alpha$ -bisabolol	1.44		
		epi- $\beta$ -santalol	2.36		
		<i>cis</i> - $\beta$ -santalol	14.50		
		<i>cis</i> -nuciferol	1.02		
		$\gamma$ -curcumen-12-ol	1.68		
		$\beta$ -curcumen-12-ol	2.35		
		camphene	3.0		
		$\beta$ -phellandrene	1.4		
		1,8-cineole	1.9		
		borneol	2.1		
		neral	7.4		
		geraniol	3.4		
		geranial	25.9		
		ar-curcumene	6.6		
		$\alpha$ -zingiberene	9.5		

Sub- stance	Plant	Chemical composition		ISO	References
		compounds	concentration, %		
		(E,E)- $\alpha$ -farnesene	7.6		
		$\beta$ -sesquiphellandrene	5.1		
		<i>trans</i> -nerolidol	1.5		
		zingiberenol	1.7		
		$\beta$ -eudesmol	1.0		
Cedar oil	<i>Cedrus atlantica</i> (Endlicher) G. Manetti ex Carrière, 1855	$\alpha$ -terpinene	1.02	9843	Derwich et al., 2010
		cis-ocimene	1.62		
		humulene	1.30		
		$\beta$ -caryophyllene	3.14		
		$\sigma$ -himachalene	7.62		
		cis- $\alpha$ -atlantone	6.78		
		himachalol	5.26		
		$\alpha$ -himachalene	4.15		
		$\alpha$ -pinene	14.85		
		$\beta$ -pinene	1.35		
		himachalene	10.14		
		cadinene	3.02		
		isocaryophyllene	1.10		
		$\beta$ -himachalene	9.89		
		germacrene-D	3.52		
		$\beta$ -copaene	2.26		
		cymene	1.05		
		3-carene	1.10		
		verbenol	2.24		
		limonene	2.01		
		ylangene	2.20		
		$\beta$ -phellandrene	2.19		
		$\gamma$ -amorphane	2.22		
Juniper oil	<i>Juniperus communis</i> Linnaeus, 1753	$\alpha$ -thujene	1.68	8897	Chatzopoulou & Katsiotis, 1993
		$\alpha$ -pinene	41.25		
		sabinene	17.38		
		$\beta$ -pinene	2.05		
		myrcene	2.66		
		$\alpha$ -terpinene	1.22		
		limonene	4.23		
		1,8-cineole	1.21		
		$\gamma$ -terpinene	2.09		
		terpinolene	1.16		
		terpinen-4-ol	2.78		
		$\beta$ -caryophyllene	1.69		
		$\alpha$ -humulene	1.56		
		germacrene D	1.83		
Geranum oil	<i>Pelargonium graveolens</i> L'Héritier, 1789	linalool	5.60	4731	Boukhris et al., 2012
		rose oxide- <i>trans</i>	2.01		
		<i>iso</i> -menthone	4.42		
		$\beta$ -citronellol	21.93		
		geraniol	11.07		
		citronellyl formate	13.24		
		geranyl formate	6.22		
		$\beta$ -bourbonene	3.14		
		<i>trans</i> -caryophyllene	1.02		
		germacrene D	4.33		
		viridiflore	2.35		
		$\delta$ -cadinene	2.38		
		$\delta$ -cadinene	1.33		
		$\alpha$ -agarofuran	1.28		
		10-epi- $\gamma$ -eudesmol	7.92		
		geranyl tiglate	2.39		
Orange oil	<i>Citrus sinensis</i> (Linnaeus) Osbeck (pro. sp.)	$\alpha$ -pinene	0.36	3140	Singh et al., 2010
		sabinene	0.37		
		$\beta$ -myrcene	1.71		
		octanal	0.43		
		limonene	90.66		
		linalylacetate	2.80		
		t-sabinene hydrate	0.42		
		laevo- $\beta$ -pinene	0.46		
		geranyl formate	0.65		
Tea tree oil	<i>Melaleuca alternifolia</i> (Maiden & Betcher) Cheel, 1925	$\alpha$ -pinene	2.1	4730	Cox et al., 2001
		$\alpha$ -terpinene	8.3		
		<i>p</i> -cymene	2.3		
		limonene	1.1		
		1,8-cineole	4.5		
		$\gamma$ -terpinene	17.8		
		$\alpha$ -terpinolene	3.3		
		terpinen-4-ol	39.8		
		$\alpha$ -terpineol	3.4		

Sub- stance	Plant	Chemical composition		ISO	References
		compounds	concentration, %		
		aromadendrene	1.2		
		viridiforene	1.2		
		$\delta$ -cadinene	1.5		
Lime oil	<i>Citrus aurantifolia</i> (Christmann) Swingle, 1913	2,3-dimethyl-2,3-butanediol	1.67	—	Sandoval-Montemayor et al., 2012
		resorcinol	3.65		
		1-methoxycyclohexene	8.00		
		linalool oxide	1.18		
		corylone	6.93		
		terpinen-4-ol	1.66		
		$\alpha$ -terpineol	5.97		
		3-methyl-1,2-cyclopentanediol	8.27		
		3,7-dimethyl-( <i>z</i> )-2,6-octadienal	1.09		
		geraniol	1.15		
		citral	2.21		
		7-methyl-( <i>Z</i> )-8-tetradecen-1-ol acetate	2.83		
		geranyl acetone	1.84		
		bergamotene	1.00		
		( <i>z</i> )-8-methyl-9-tetradecenoic acid	1.24		
		<i>trans</i> - $\alpha$ -bisabolene	1.02		
		caryophyllene oxide	3.02		
		spathulenol	1.95		
		umbelliferone	4.36		
		palmitic acid	6.89		
		5,7-dimethoxycoumarin	15.80		
		5-methoxypsoralen	1.14		
		5,8-dimethoxypsoralen	6.08		
Pepper mint oil	<i>Mentha piperita</i> Linnaeus, 1753	1,8 cineole	6.69	856	Saharkhiz et al., 2012
		menthone	2.45		
		menthofuran	11.18		
		neomenthol	2.79		
		menthol	53.28		
		menthyl acetate	15.10		
		( <i>z</i> )-caryophyllene	2.06		
		germacrene D	2.01		
Jojoba oil	<i>Simmondsia chinensis</i> (Link) C. K. Schneider, 1912	saturated acids (C <sub>20</sub> –C <sub>26</sub> )	1.64	—	Knoepfler et al., 1958
		palmitoleic acid	0.24		
		oleic acid	0.66		
		eicosenoic acid	30.30		
		docosenoic acid	14.20		
		eicosenol	14.60		
		docosenol	33.70		
		hexacosenol	2.00		
Lemon oil	<i>Citrus limon</i> (Linnaeus) Osbeck, 1765	$\beta$ -pinene	5.20	855	Espina et al., 2011
		<i>p</i> -cymene	3.29		
		limonene	59.10		
		$\gamma$ -terpinene	9.66		
		<i>cis-p</i> -mentha-1(7),8-dien-2-ol	1.33		
		geraniol	2.11		
		<i>cis</i> -thujopsene	2.38		
		$\beta$ -bisabolene	3.61		
Lavender oil	<i>Lavandula angustifolia</i> Miller, 1768	camphene	1.37	3515	Jianu et al., 2013
		$\beta$ -myrcene	2.03		
		D-limonene	2.10		
		$\beta$ -phellandrene	16.00		
		1,8-cineole	15.69		
		terpinen-4-ol	9.57		
		borneol	5.07		
		$\alpha$ -terpineol	6.00		
		santalene	4.50		
		caryophyllene	24.12		
Almond oil	<i>Prunus dulcis</i> (Miller) D. A. Webb, 1967	myristic acid	0.0–0.07	—	Fernandes et al., 2017
		palmitic acid	4.7–15.8		
		palmitoleic acid	0.1–2.5		
		stearic acid	0.3–2.5		
		oleic acid	50.4–81.2		
		linoleic acid	6.2–37.1		
		linolenic acid	0.0–11.1		
		arachidic acid	0.04–0.20		
		campesterol	2.5		
		stigmastanol	2.5		
		$\beta$ -sitosterol	55.9–95.1		
		$\Delta$ 5-avenasterol	8.5–28.2		
		$\alpha$ -tocopherol	97.3		
		$\gamma$ -tocopherol	2.8		

Note: \* – number of ISO standard.

Each cup was covered with a separate plastic cover to prevent mixing of odours of essential oils. The experiment was made in five replications (n = 10, i.e. five tests with two replications for each essential oil). The duration of each experiment was 48 hours. At the end of this period, the flour from the cups was sieved for counting live and dead insects.

At the second stage of our research, we evaluated the influence on movement activity of *T. confusum* by the most efficient essential oils found at the first stage. In the container, we put wheat flour in 1 cm layer and 45 cups with 25 imagoes of *T. confusum*, of which 40 contained cotton pads processed with essential oil (one variant in four cups), and five cups – control. We used the earlier found repellent (*J. officinale*, *R. officinalis*, *T. occidentalis*, *M. alternifolia*, *C. verum*, *L. angustifolia*) and attractant (*Z. officinale*, *C. atlantica*, *J. communis*, *C. sinensis*) essential oils. The experiment which lasted 24 hours was made in three replications (n = 12, i.e. four cups in three experiments for each of the 10 essential oils).

At the third stage, we checked the patterns found earlier in the effect of the essential oils on the migration activity of *T. confusum* imagoes. In the experiment, we used polyethylene tubes of 4 cm in diameter and 150 cm in length with measurement marks put at each 10 cm of length. On either ends of the tubes, a cotton disk with essential oil was put: with a repellent on one, and with an attractant on the other. Evaporations of the following essential oils were used, selected during the two previous stages: thuja – ginger and jasmine – cedar. Each variant of the experi-

ment lasted 24 h and was performed in eight replications (n = 8). By the end of the experiment, for each 10 cm of tube, the flour was collected and sieved through a laboratory sieve for measuring its presence in each section. All stages of the experiment were conducted in the laboratory with constant illumination and temperature, out of reach of direct sun light. Fluctuations in temperature over 24 hours did not exceed 2 °C (+21...+23 °C), duration of daylight in October–November 2018 was 8.30–11.00 hours and was prolonged to 14 h a day by artificial illumination, and air humidity equaled 60–70%.

The results were statistically analyzed in Statistica 8.0 software (Statsoft Inc., USA). Differences between the selections were considered reliable at P < 0.05 (one-way ANOVA).

## Results

The property of the studied essential oils to attract or repel *T. confusum* (Fig. 1) at the first stage of the experiment allowed us to determine that repellent activity against *T. confusum* imago was exhibited by essential oils of *J. officinale*, *R. officinalis*, *T. occidentalis*, *M. alternifolia*, *L. angustifolia* and *C. verum*. Attractant property was also demonstrated by essential oils of *J. communis*, *Z. officinale*, *C. sinensis* and *C. atlantica*. The rest of the examined essential oils had no significant effect on movement activity of *T. confusum*.

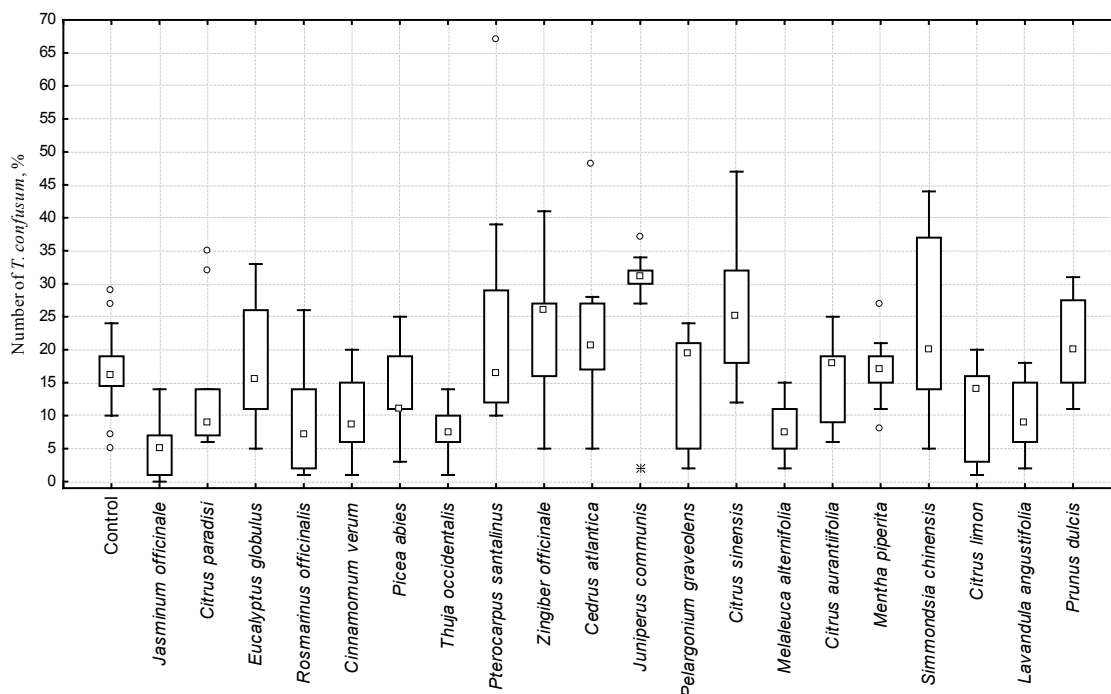


Fig. 1. Effect of essential oils on migratory ability of *T. confusum* in 48 h laboratory experiment

At the second stage of the research, we determined that the most active repellents against *T. confusum* were essential oils of *T. occidentalis* and *J. officinale*, and the most active attractants – essential oils of *Z. officinale* and *C. atlantica* (Fig. 2, 3, Table 2, 3).

At third stage, we studied distribution of *T. confusum* under simultaneous effect of repellent and attractant essential oils in evaporations of thuja-ginger and jasmine-cedar. Essential oil of *T. occidentalis* repelled imagoes at a distance of up to 30 cm. Essential oil from *Z. officinale* lured insects, but with low efficiency: attractant properties were exhibited at a distance of up to 20 cm (Fig. 4). Essential oil of *J. officinale* exhibited repellent properties at a distance of up to 20 cm, and *C. atlantica* lured insects with the same efficiency as oil of *Z. officinale* (Fig. 5).

## Discussion

The data we obtained indicate that essential oils of *J. officinale* and *T. occidentalis* exert notable repellent activity on *T. confusum* at low concentrations, whereas essential oils of *Z. officinale* and *C. atlantica* attract insects.

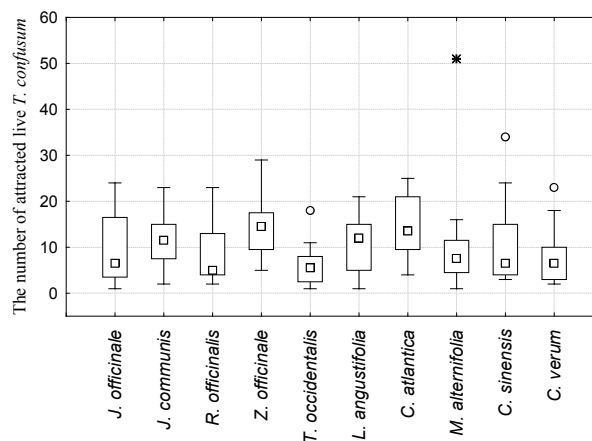
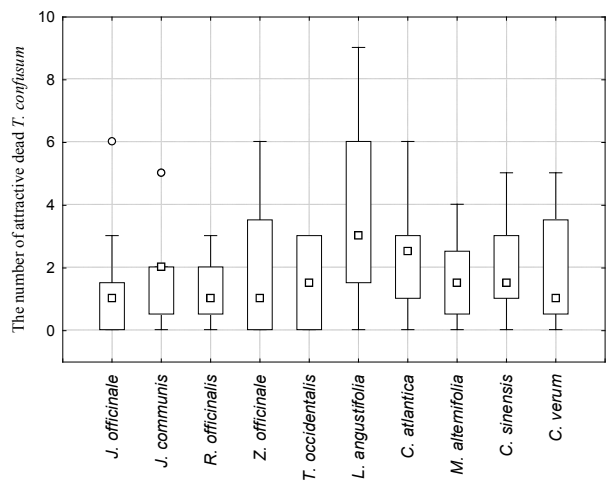


Fig. 2. Attractant effect of essential oils on *T. confusum* in conditions of laboratory experiment

Absence of notable effects in the rest of the examined samples can be related to insufficient concentration of essential oils or resistance of this pest species. Resistance of the insects to evaporations of essential oils can be related to activity of cytochrome P<sub>450</sub>-dependent monooxygenase, carboxyl esterase, superoxide dismutase and catalase (Ryan & Byrne, 1988; Boyer et al., 2011).



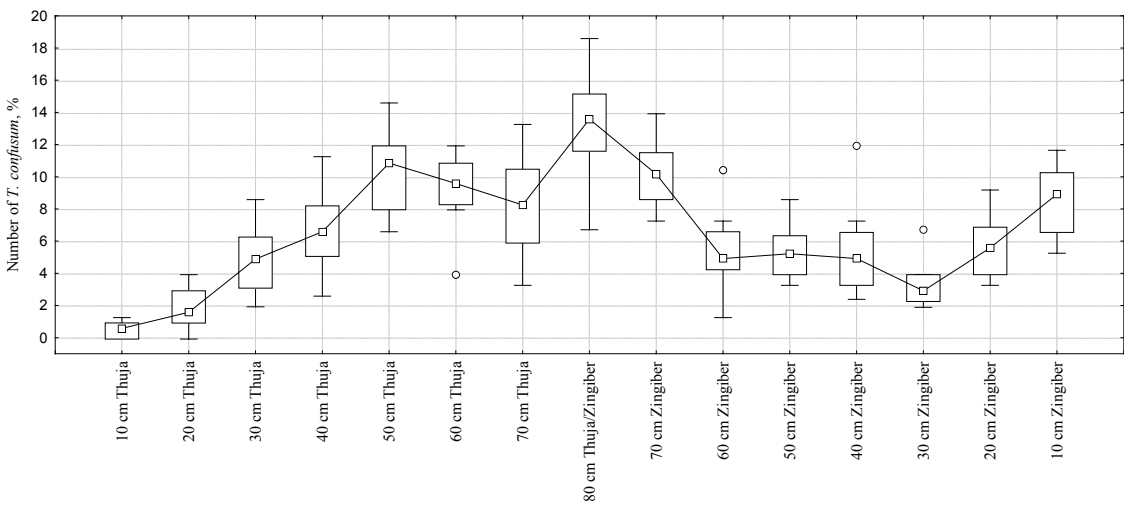
**Fig. 3.** Attractant effect of essential oils on *T. confusum* in conditions of laboratory experiment

**Table 2**  
Effect of essential oils on distribution of *T. confusum* in the food substrate

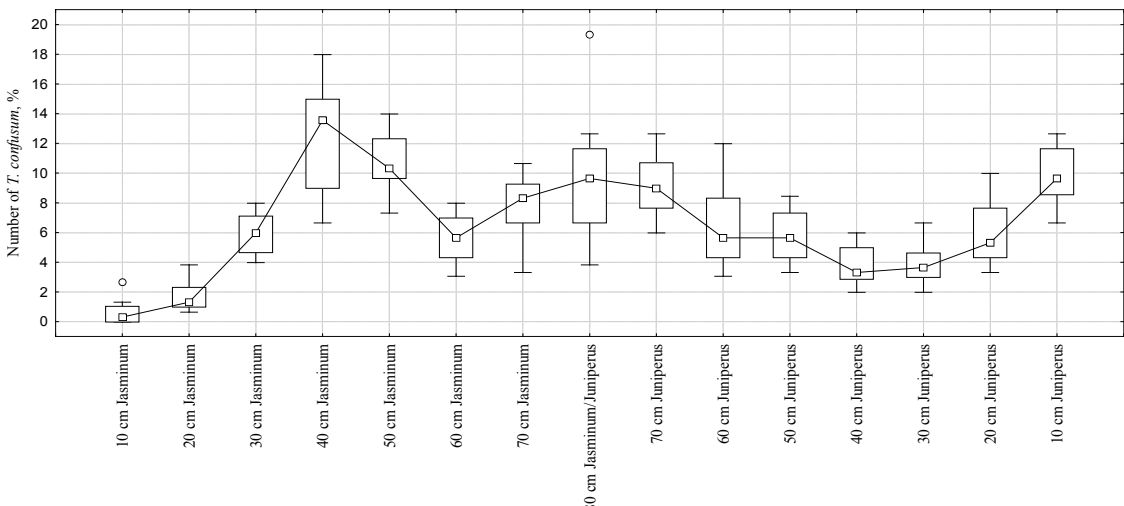
Essential oil	Number of attracted individuals ( $\bar{x} \pm SD$ ), spec.	P	F	F <sub>0.05</sub>
<i>Citrus sinensis</i>	8.92 $\pm$ 8.88	0.161	1.489	1.966
<i>Jasminum officinale</i>	8.67 $\pm$ 8.72			
<i>Zingiber officinale</i>	13.08 $\pm$ 7.83			
<i>Cedrus atlantica</i>	12.42 $\pm$ 6.39			
<i>Cinnamomum verum</i>	6.33 $\pm$ 5.40			
<i>Lavandula angustifolia</i>	6.83 $\pm$ 4.17			
<i>Rosmarinus officinalis</i>	7.58 $\pm$ 6.46			
<i>Thuja occidentalis</i>	4.50 $\pm$ 4.03			
<i>Melaleuca alternifolia</i>	9.50 $\pm$ 12.49			
<i>Juniperus communis</i>	9.92 $\pm$ 6.91			

**Table 3**  
Effect of essential oils on distribution of dead individuals of *T. confusum* in food substrate

Essential oil	Number of attracted individuals ( $\bar{x} \pm SD$ ), spec.	P	F	F <sub>0.05</sub>
<i>Citrus sinensis</i>	1.92 $\pm$ 1.62	0.056	1.922	1.966
<i>Jasminum officinale</i>	1.33 $\pm$ 1.70			
<i>Zingiber officinale</i>	1.83 $\pm$ 2.00			
<i>Cedrus atlantica</i>	2.33 $\pm$ 1.56			
<i>Cinnamomum verum</i>	1.92 $\pm$ 1.88			
<i>Lavandula angustifolia</i>	3.67 $\pm$ 2.81			
<i>Rosmarinus officinalis</i>	1.25 $\pm$ 1.14			
<i>Thuja occidentalis</i>	1.58 $\pm$ 1.38			
<i>Melaleuca alternifolia</i>	1.58 $\pm$ 1.31			
<i>Juniperus communis</i>	1.58 $\pm$ 1.38			



**Fig. 4.** Effect of essential oils of *T. occidentalis* and *Z. officinale* on distribution of *T. confusum* in fodder substrate



**Fig. 5.** Effect of essential oils from *J. officinale* and *C. atlantica* on distribution of *T. confusum* in fodder substrate

Effect of essential oils and their components on *T. confusum* and other economically harmful species is described in a number of publications. Haouas et al. (2007) studied biological activity of essential oils from *Chrysanthemum* spp. against *T. confusum*. Most efficient was the essential oil obtained from leaves of *Ch. grandiflorum*, which caused decrease in tempi of growth (by 0.03 mg/mg/24 hours), efficiency of consumption of food (by 50.7%), amount of ration consumed (by 66.4%) and increase in mortality of *T. confusum* larvae up to 80% after 7 days of the experiment. Under exposure to essential oil of leaves of *Ch. coronarium*, mortality reached 18%. Contact toxicity of essential oil of *Ch. grandiflorum* in 1% concentration equaled 27% after 7 days.

In a study of contact toxicity of essential oil of *Eucalyptus saligna* for *T. confusum*, Tapondjou et al. (2001) determined that complete mortality of insects was achieved at a dose of 0.78 and 1.56 mL/cm<sup>2</sup> over 4 days. Furthermore, cymol, one of the main components of the studied oil, in 1.30 mL/cm<sup>2</sup> concentration caused complete death of *T. confusum* after 24 hours.

Khani et al. (2017) studied toxicity and repellency of essential oils of *Juniperus polycarpus* and *J. sabina* against *T. confusum*. Mortality significantly increased with increase in concentration and duration of influence. Highest mortality (90%) was achieved at impact of essential oil of *J. polycarpus* in 611 mL/L of air and 82% at impact of oil from *J. sabina* in concentration 666  $\mu$ L/L of air after 24 hours. Values of LC<sub>50</sub> for essential oils from *J. polycarpus* and *J. sabina* equaled 368.4 and 301.9  $\mu$ L/L of air, respectively. Repellency of the tested substances depended on the concentration and equaled 96.0% at concentration of 15  $\mu$ L/L of acetone and 6.7% and 10.0% at 1  $\mu$ L/L concentration of essential oils from *J. polycarpus* and *J. sabina* respectively.

Isikber et al. (2006) investigated toxicity of essential oils of bay laurel (*L. nobilis*) and rosemary (*R. officinalis*) for different stages of *T. confusum*. Highest mortality (95.0%) after 24 hours of exposure was achieved at maximum tested concentration of essential oil from *R. officinalis* (431.5 mg/L of air), whereas essential oil of *L. nobilis* caused only 15.5% mortality in the same conditions. These parameters are related to insufficient time of exposure. The highest resistance to essential oil of rosemary, was presented by pupae, with LT<sub>90</sub> equaling 89.5 hours at 172.6 mg/L of air, whereas imagoes were more sensitive (LT<sub>90</sub> = 37.5 hours). Against essential oil of bay laurel, the most resistant were larvae (LT<sub>90</sub> = 77.2 hours), whereas pupae were more sensitive (LT<sub>90</sub> = 39.3 hours). Though essential oils from *L. nobilis* and *R. officinalis* have fumigant toxicity for all life stages of *T. confusum*, with different effectiveness, causing complete death of the insects requires using high doses.

Insecticidal action of essential oil from *C. sinensis* on *T. confusum* was researched by Oboh et al. (2017). At concentrations of 50 and 75  $\mu$ L/L of air, essential oil exhibited moderate insecticidal activity: 50% and 60% mortality respectively after 24 h of impact. At maximum concentration of 150  $\mu$ L/L of air, insecticidal activity was high with 100% mortality and LC<sub>50</sub> 38.9, 26.9 and 14.5  $\mu$ L/L after 24, 48 and 72 hours of impact respectively. Also there was studied inhibiting activity of acetylcholinesterase and Na<sup>+</sup>/K<sup>+</sup>-ATPase of *T. confusum* exposed to essential oil of *C. sinensis*: IC<sub>50</sub> for these enzymes equaled 7.94 and 60.25  $\mu$ L/L of air, respectively. Yunis (2014) studied impact of essential oil of *C. sinensis* on *T. confusum*: essential oil in 10% concentration caused 70.0%, 86.6% and 100.0% mortality after 1, 2 and 3 days, respectively. In a study of toxicity of essential oil of *C. sinensis* for *T. confusum*, *Callosobruchus maculatus* (Fabricius, 1775) and *Rhyzopertha dominica*, Tandorost & Karimpour (2012) determined that LC<sub>50</sub> equaled 259, 158 and 124  $\mu$ L/L of air after 24 hours of impact and 134, 106 and 93  $\mu$ L/L of air after 48 hours for each insect respectively. Highest mortality was achieved using concentrations 53, 41 and 31  $\mu$ L<sup>-1</sup> against *T. confusum*, *C. maculatus* and *R. dominica*, respectively after 48 hours of exposure.

Campolo et al. (2013) studied biological activity of essential oils from five species of *Citrus* spp. against *T. confusum*. Maximum mortality was reached after 24 hours at absence of flour and concentration of  $17.2 \cdot 10^{-3}\%$  of essential oils from *C. sinensis*, *C. aurantium* and *C. limon*. Addition of 10 mm of flour reduced efficiency, and 100% mortality was caused by maximum concentration of  $69.0 \cdot 10^{-3}\%$  for these

samples. LD<sub>50</sub> equaled 4.03, 4.08 and 5.09, and LD<sub>90</sub> for *C. sinensis*, *C. aurantium* and *C. limon* equaled 11.14, 11.90 and 15.46 respectively.

Russo et al. (2015) tested insecticidal action of essential oil from *Eucalyptus globulus* on *T. confusum*. Insecticidal effect increased depending on time and concentration of the studied substance. High concentration of 1.25  $\mu$ L/cm<sup>2</sup> eliminated 90% of the pests after 30 minutes of exposure. After two hours of exposure, mortality close to maximum (98.3%) was reached by a lower concentration of 1.00  $\mu$ L/cm<sup>2</sup>, whereas at four-hour exposure, 100% mortality required 0.75  $\mu$ L/cm<sup>2</sup>.

Fathi & Shakarami (2014) undertook a research on larvicidal effect of essential oils of *Eucalyptus* spp. for *T. confusum* and *T. castaneum*. Larvae of *T. confusum* were more sensitive than *T. castaneum*. After 24 hours of exposure, LC<sub>50</sub> for essential oils of *E. camaldulensis*, *E. viminalis*, *E. microtheca*, *E. grandis* and *E. sargentii* against larvae of *T. confusum* were 41.5, 20.7, 53.4, 26.4 and 110.5  $\mu$ L/L of air respectively, whereas values of LC<sub>50</sub> of these essential oils for larvae of *T. castaneum* equaled 110.3, 48.1, 117.0, 71.9 and 155.8  $\mu$ L/L of air, respectively.

Khalis Ali (2013) explored toxicity of different plant extracts for *T. confusum*. Indicators of maximum mortality ranged depending on the plant species, therefore for *Anethum graveolens*, it equaled 56.7% at 4.5 hours exposure, for *Apium graveolens* – 93.3% after 5 h, *Eucalyptus glauca* – 90.0% after 2 h, *Malva parviflora* – 96.7% after 3 h, *M. longifolia* – 93.3% after 4 h and for *Z. officinalis* – 100% after 2 h.

Khani et al. (2012) studied toxicity of essential oil from *Aloysia citrodora* Palau, 1784 for *T. confusum* and *Callosobruchus maculatus*. It was determined that *C. maculatus* was more sensitive for this fumigant (LC<sub>50</sub> = 10.2  $\mu$ L/L of air) than *T. confusum* (LC<sub>50</sub> = 497.8  $\mu$ L/L of air) at 24 h impact.

Karci & Isikber (2007) researched ovicidal activity of different essential oils in concentration of 100  $\mu$ L/L of air against *T. confusum* over 24, 48 and 72 h. Strong ovicidal effect was exhibited by essential oils from *Allium sativum*, *A. cepa*, *Pimpinella anisum*, *Origanum dubium* and *Foeniculum vulgare*, with mortality parameters equaling 99.3%, 100.0%, 95.6%, 100.0% and 96.9% after 72 h of exposure and LT<sub>90</sub> equaling 1.1, 22.1, 22.4, 13.8 and 51.1 h, respectively. Isikber et al. (2009) studied ovicidal action of different essential oils in concentration of 20  $\mu$ L/L of air on *T. confusum* over 24 h. Use of essential oils of *A. sativum*, *Betula lenta* and *Cinnamomum zeylanicum* caused 100% mortality of the insects, whereas for *Pimpinella anisum*, this parameter equaled  $50.7 \pm 1.8\%$ . Values of LC<sub>90</sub> for essential oils of *A. sativum*, *B. lenta*, *C. zeylanicum* and *P. anisum* were 6.9, 4.5, 3.1 and 33.5  $\mu$ L/L of air respectively.

Stamopoulos et al. (2007) studied biological effect of five monoterpenoids, components of essential oils, against different stages of *T. confusum*. The most toxic for all studied stages were terpinen-4-ol with LC<sub>50</sub> in range of 1.1–109.4  $\mu$ L/L of air, (R)-(+)-limonene (LC<sub>50</sub> – 4–278  $\mu$ L/L of air) and 1.8-cineole (LC<sub>50</sub> – 3.5–466  $\mu$ L/L of air). Toxicity of linalool was lower with LC<sub>50</sub> in range of 8.6–183.5  $\mu$ L/L, and geraniol was the least toxic: LC<sub>50</sub> – 607–1627  $\mu$ L/L of air. In all cases, except geraniol, most sensitive stage was third age larvae, and most tolerant – three-days old eggs. Also, a reduction of fertility and production of eggs was observed under the effect of evaporations of tested substances. Tripathi et al. (2001) investigated contact toxicity, fumigant and antifeedant activity of 1.8-cineole extracted from *Artemisia annua* against *T. castaneum*. The study revealed that adult individuals were more sensitive to 1.8-cineole than larvae. At 121.9 mg/g concentration, antifeedant effect for imago equaled 81.9%. 1.8-Cineole applied to the filter paper in 3.2–16.1 mg/cm<sup>2</sup> concentration significantly reduced number of matured eggs.

Malacrinò et al. (2016) studied toxicity of enantiomers of limonene, a component of different essential oils, against *T. confusum*. Mortality of insects depended on concentration of substance and temperature. In tests without flour, R-(+)-limonene caused 100% mortality at 20 °C and concentration equaling 85 mg/L of air, whereas mortality at impact of S-(–)-limonene was  $80.0 \pm 2.5\%$  in the same conditions and heightened with increase in temperature up to  $88.0 \pm 4.9\%$  at 30 °C and to 100% at 40 °C. Mortality caused by R-(+)-limonene at 40 °C reached maximum already at concentration of 42.5 mg/L of air. Addition of



flour significantly reduced the parameters. At presence of 10 mm layer of flour and temperatures of 20 and 30 °C, no mortality of *T. confusum* was observed, whereas at 40 °C, effectiveness of R-(+)-limonene and S-(-)-limonene equaled  $86.0 \pm 2.5\%$  and  $66.0 \pm 6.8\%$ , respectively at maximum concentration (85 mg/L of air).

Kalita & Bhola (2012) investigated toxicity and repellence of different plant extracts for *T. castaneum*. Highest parameters of mortality of insects were obtained using extracts from *Viola arvensis* (68%), *M. chamomilla* (57%), *Brassica campestris* (56%) and *Jacaranda mimosifolia* (49%) after 7 days of impact. Furthermore, *J. mimosifolia*, *M. chamomilla* and *Tagetes minuta* exhibited high repellence (IR = 0.04) against *T. castaneum*. In the research by Al-Jabr (2006) on toxicity and repellence of different essential oils, *M. chamomila* had high repellence, equaling 81.9 and 84.7 at 1.0% concentration, against *O. surinamensis* and *T. castaneum* respectively.

Bhaskar Mi & Tripathi (2011) studied repellence of different essential oils for *Sitophilus oryzae* (Linnaeus, 1763) and *T. castaneum*. At highest tested concentration (0.2%) of essential oils from *S. aromaticum*, *A. marmelos*, *C. sativum* and *C. reticulata*, their repellence equaled 90.0%, 85.0%, 83.3% and 78.3% for *S. oryzae*, and 90.0%, 86.6%, 83.3% and 80.0% for *T. castaneum* respectively.

Maedeh et al. (2012) evaluated toxicity and repellence of essential oil from *Z. officinale* against *T. castaneum*. Values of LC<sub>50</sub> and LC<sub>90</sub> after 48 hours were assessed as 374.9 and 1124.2 µL/L of air, respectively. Repellence of essential oil was high even at low concentrations and reached 85% at 1.6 µL/L of air.

Wang et al. (2006) investigated fumigant and repellent action of essential oil from *A. vulgaris* on *T. castaneum*. Essential oil in concentration of 0.6 µg/mL and higher efficiently repelled the insects, and 100% mortality of imagoes was caused at 8.0 µg/mL. Mortality of larvae of different ages equaled 49–52%. The oil also had high fumigant activity against eggs of *T. castaneum* and caused 100% mortality at concentrations of 10, 15 and 20 g/L of air over 96 h.

Huang & Ho (1998) evaluated toxicity and antifeedant activity of cinnamaldehyde (one of the components of essential oil from *C. verum*) against *T. castaneum*. Cinnamaldehyde had no antifeedant effect on imagoes of *T. castaneum* in concentration up to 13.6 mg/g of fodder, though it significantly reduced consumption of food and growth of larvae in concentrations of 27.2 and 54.4 mg/g of fodder. With increase in concentration of cinnamaldehyde, antifeedant effect increased.

Arabi et al. (2008) studied insecticidal activity of essential oil from *Perovskia abrotanoides* Karelín (1841) against *S. oryzae* and *T. castaneum*. Maximum concentration of 645 mL/L of air eliminated 80% of *T. castaneum* after five hours of exposure, whereas for *S. oryzae*, this parameter equaled around 10% in the same conditions. Maximum mortality was obtained using 322 µL/L concentration over 7 and 13 h, respectively. Values of LT<sub>50</sub> for *S. oryzae* ranged from 8 hours for highest concentration (645 µL/L of air) to 11.5 hours at lowest concentration (32 µL/L of air), whereas for *T. castaneum*, LT<sub>50</sub> was achieved in 4.5 hours (32 µL/L of air) and 2.8 hours (645 µL/L of air), which confirms the high sensitivity of *T. castaneum* to the fumigant compared to *S. oryzae*.

Kéita et al. (2001) investigated insecticidal effect of essential oil from *T. occidentalis* against *C. maculatus*. Using 100 g of kaolin powder aromatized with 3 µL of essential oil caused 95% mortality among females and 100% among males after 6 hours of exposure. LD<sub>50</sub> for essential oil from *T. occidentalis* was 323, 162 and 52 µL/g at 12, 24 and 48 hours of exposure.

Abou-Taleb et al. (2015) studied toxicity of various essential oils for *T. castaneum* and determined that the most efficient were essential oils from *O. vulgare* (LC<sub>50</sub> = 9.9 mg/L of air), *C. sinensis* (LC<sub>50</sub> = 24.6 mg/L), *C. lemon* (LC<sub>50</sub> = 25.5 mg/L) and *M. communis* (LC<sub>50</sub> = 26.5 mg/L of air). Parameters of inhibition of acetylcholinesterase (IC<sub>50</sub>) for *C. aurantifolia*, *C. lemon*, *O. vulgare* and *R. officinalis* equaled 105.8, 35.3, 24.4 and 20.8 mg/L, and for inhibition of ATPases – 44.4, 10.2, 10.2 and 11.4 mg/L respectively.

Despite the relevance of analysis of methods of using essential oils or their components as insecticidal preparations, their introduction into technology of integrated pest control remains impossible due to the

insufficient amount of information on this problem, and difficulty of standardizing and ensuring quality control of the plant products.

## Conclusions

Notable repellent activity against *T. confusum* has been demonstrated by essential oils from *J. officinale* and *T. occidentalis* at concentration of 0.48 mL/cm<sup>2</sup>. Essential oils from *Z. officinale* and *C. atlantica* attracted the insect. We observed manifestations of repellent properties of essential oils from *R. officinalis*, *M. alternifolia*, *L. angustifolia* and *C. verum*, and that essential oils of *J. communis* and *C. sinensis* attracted the pest. Thus, out of 20 studied essential oils, only four samples had notable biological effect on migratory ability of *T. confusum*. These data support a lot of other research on insecticidal activity of essential oils and possibility of using them as natural pesticides. Study of biological activity of essential oils against economically harmful species of insects is a relevant task necessary for development of ecologically-based pest control.

## References

- Abdossi, V., Moghaddam, E. Y., & Hadipanah, A. (2015). Chemical composition of *Eucalyptus globulus* grown in Iran. *Biological Forum – An International Journal*, 7(2), 322–324.
- Abou-Taleb, H. K., Mohamed, M. I. E., Shawir, M. S., & Abdelgaleil, S. A. M. (2015). Insecticidal properties of essential oils against *Tribolium castaneum* (Herbst) and their inhibitory effects on acetylcholinesterase and adenosine triphosphatases. *Natural Product Research*, 30(6), 710–714.
- Al-Jabr, A. M. (2006). Toxicity and repellency of seven plant essential oils to *Oryzaephilus surinamensis* (Coleoptera: Silvanidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae). *Scientific Journal of King Faisal University*, 7(1), 49–60.
- Arabi, F., Moharramipour, S., & Sefidkon, F. (2008). Chemical composition and insecticidal activity of essential oil from *Perovskia abrotanoides* (Lamiaceae) against *Sitophilus oryzae* (Coleoptera: Curculionidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae). *International Journal of Tropical Insect Science*, 28(3), 144.
- Bakkali, F., Averbeck, S., Averbeck, D., & Idaomar, M. (2008). Biological effects of essential oils – A review. *Food and Chemical Toxicology*, 46(2), 446–475.
- Benhalima, H., Chaudhry, M. Q., Mills, K. A., & Price, N. R. (2004). Phosphine resistance in stored-product insects collected from various grain storage facilities in Morocco. *Journal of Stored Products Research*, 40(3), 241–249.
- Bhaskar Mi, B., & Tripathi, S. P. (2011). Repellent activity of plant derived essential oils against *Sitophilus oryzae* (Linnaeus) and *Tribolium castaneum* (Herbst). *Singapore Journal of Scientific Research*, 1(2), 173–178.
- Boukhris, M., Simmonds, M. S. J., Sayadi, S., & Bouaziz, M. (2012). Chemical composition and biological activities of polar extracts and essential oil of rose-scented geranium, *Pelargonium graveolens*. *Phytotherapy Research*, 27(8), 1206–1213.
- Boyer, S., Zhang, H., & Lemprière, G. (2011). A review of control methods and resistance mechanisms in stored-product insects. *Bulletin of Entomological Research*, 102(2), 213–229.
- Brygadyrenko, V., & Ivanyshyn, V. (2015). Changes in the body mass of *Megaphyllium kievense* (Diplopoda, Julidae) and the granulometric composition of leaf litter subject to different concentrations of copper. *Journal of Forest Science*, 61(9), 369–376.
- Burt, S. (2004). Essential oils: Their antibacterial properties and potential applications in foods – A review. *International Journal of Food Microbiology*, 94(3), 223–253.
- Campolo, O., Malacrino, A., Zappalà, L., Laudani, F., Chiera, E., Serra, D., & Palmeri, V. (2013). Fumigant bioactivity of five *Citrus* essential oils against *Tribolium confusum*. *Phytoparasitica*, 42(2), 223–233.
- Chatzopoulou, P. S., & Katsiotis, S. T. (1993). Chemical investigation of the leaf oil of *Juniperus communis* L. *Journal of Essential Oil Research*, 5(6), 603–607.
- Cox, S. D., Mann, C. M., & Markham, J. L. (2001). Interactions between components of the essential oil of *Melaleuca alternifolia*. *Journal of Applied Microbiology*, 91(3), 492–497.
- Derwich, E., Benziane, Z., & Boukir, A. (2010). Chemical composition and *in vitro* antibacterial activity of the essential oil of *Cedrus atlantica*. *International Journal of Agriculture and Biology*, 12, 381–385.
- Ebadollahi, A., & Jalali Sendi, J. (2015). A review on recent research results on bio-effects of plant essential oils against major coleopteran insect pests. *Toxin Reviews*, 34(2), 76–91.
- Espina, L., Somolinos, M., Lorán, S., Conchello, P., García, D., & Pagán, R. (2011). Chemical composition of commercial citrus fruit essential oils and evaluation

- of their antimicrobial activity acting alone or in combined processes. *Food Control*, 22(6), 896–902.
- Fathi, A., & Shakarami, J. (2014). Larvicidal effects of essential oils of five species of *Eucalyptus* against *Tribolium confusum* (du Val) and *T. castaneum* (Herbst). *International Journal of Agriculture and Crop Sciences*, 7(5), 220–224.
- Fernandes, G. D., Gómez-Coca, R. B., Pérez-Camino, M. del C., Moreda, W., & Barrera-Arellano, D. (2017). Chemical characterization of major and minor compounds of nut oils: Almond, hazelnut, and pecan nut. *Journal of Chemistry*, 2017, 1–11.
- Gachkar, L., Yadegari, D., Rezaei, M., Taghizadeh, M., Astaneh, S., & Rasooli, I. (2007). Chemical and biological characteristics of *Cuminum cyminum* and *Rosmarinus officinalis* essential oils. *Food Chemistry*, 102(3), 898–904.
- Grdiša, M., & Gršić, K. (2013). Botanical insecticides in plant protection. *Agriculturae Conspectus Scientificus*, 78(2), 85–93.
- Gutiérrez, M. M., Werdin-González, J. O., Stefanazzi, N., Bras, C., & Ferrero, A. A. (2015). The potential application of plant essential oils to control *Pediculus humanus capitis* (Anoplura: Pediculidae). *Parasitology Research*, 115(2), 633–641.
- Hana, H., & Mohammed, H. H. M. (2013). Repellency of ethanolic extract of some indigenous plants against *Tribolium confusum* (du Val) (Coleoptera: Tenebrionidae). *IOSR Journal of Agriculture and Veterinary Science*, 2(6), 27–31.
- Haouas, D., Cioni, P. L., Ben Halima-Kamel, M., Flamini, G., & Ben Hamouda, M. H. (2012). Chemical composition and bioactivities of three *Chrysanthemum* essential oils against *Tribolium confusum* (du Val) (Coleoptera: Tenebrionidae). *Journal of Pest Science*, 85(3), 367–379.
- Huang, Y., & Ho, S. H. (1998). Toxicity and antifeedant activities of cinnamaldehyde against the grain storage insects, *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* Motsch. *Journal of Stored Products Research*, 34(1), 11–17.
- Isikber, A. A., Alma, M. H., Kanat, M., & Karci, A. (2006). Fumigant toxicity of essential oils from *Laurus nobilis* and *Rosmarinus officinalis* against all life stages of *Tribolium confusum*. *Phytoparasitica*, 34(2), 167–177.
- Isikber, A. A., Önder, N., & Sağlam, Ö. (2009). Susceptibility of eggs of *Tribolium confusum*, *Ephestia kuehniella* and *Plodia interpunctella* to four essential oil vapors. *Phytoparasitica*, 37(3), 231–239.
- Isman, M. B. (1997). Neem and other botanical insecticides: Barriers to commercialization. *Phytoparasitica*, 25(4), 339–344.
- Isman, M. B. (2000). Plant essential oils for pest and disease management. *Crop Protection*, 19, 603–608.
- Isman, M. B. (2004). Plant essential oils as green pesticides for pest and disease management. *Agricultural Applications in Green Chemistry*, 4, 41–51.
- Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology*, 51(1), 45–66.
- Isman, M. B. (2007). Botanical insecticides: For richer, for poorer. *Pest Management Science*, 64(1), 8–11.
- Jayaprakash, G. K., Rao, L. J., & Sakariah, K. K. (2002). Chemical composition of volatile oil from *Cinnamomum zeylanicum* buds. *Zeitschrift Für Naturforschung*, C 57, 990–993.
- Jianu, C., Pop, G., Gruia, A. T., & Horhat, F. G. (2013). Chemical composition and antimicrobial activity of essential oils of lavender (*Lavandula angustifolia*) and lavandin (*Lavandula x intermedia*) grown in Western Romania. *International Journal of Agriculture and Biology*, 15, 772–776.
- Jirovetz, L., Buchbauer, G., Denkova, Z., Slavchev, A., Stoyanova, A., & Schmidt, E. (2006). Chemical composition, antimicrobial activities and odor descriptions of various *Salvia* sp. and *Thuja* sp. essential oils. *Nutrition*, 30(4), 152–159.
- Kalita, S., & Bhola, R. K. B. (2012). Repellency and toxicity of some plant extracts against *Tribolium castaneum* (Herbst). *Global Journal for Research Analysis*, 3(6), 216–217.
- Karci, A., & Isikber, A. A. (2007). Ovicidal activity of various essential oils against confused flour beetle, *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae). *Integrated Protection of Stored Products*, 30(2), 251–258.
- Kaufmann, C., & Briegel, H. (2004). Flight performance of the malaria vectors *Anopheles gambiae* and *Anopheles atroparous*. *Journal of Vector Ecology*, 29(1), 140–153.
- Kéita, M. S., Vincent, C., Schmidt, J. P., & Thor Amason, J. (2001). Insecticidal effects of *Thuja occidentalis* (Cupressaceae) essential oil on *Callosobruchus maculatus* [Coleoptera: Bruchidae]. *Canadian Journal of Plant Science*, 81(1), 173–177.
- Khalis Ali, W. (2013). Toxic effect of some plant extracts on the mortality of flour beetle *Tribolium confusum* (duVal) (Coleoptera: Tenebrionidae). *Entomology, Ornithology and Herpetology*, 2, 115.
- Khani, A., Basavand, F., & Rakhshani, E. (2012). Chemical composition and insecticide activity of lemon *Verbena* essential oil. *Journal of Crop Protection*, 1(4), 313–320.
- Khani, A., Rashid, B., & Mirshekar, A. (2017). Chemical composition and insecticidal efficacy of *Juniperus polycarpus* and *Juniperus sabina* essential oils against *Tribolium confusum* (Coleoptera: Tenebrionidae). *International Journal of Food Properties*, 20(S2), S1221–S1229.
- Klocke, J. A. (1989). Plant compounds as sources and models of insect-control agents. In: Wagner, H., Hikino, H., & Farnsworth, N. (Eds.). *Economic and medicinal plant research*. Academic Press. Vol. 3. Pp. 104–144.
- Knoepfler, N. B., & Vix, H. L. E. (1958). Vegetable oils, review of chemistry and research potential of *Simmondsia chinensis* (jojoba) oil. *Journal of Agricultural and Food Chemistry*, 6(2), 118–121.
- Koul, O., & Walia, S. (2009). Comparing impacts of plant extracts and pure allelochemicals and implications for pest control. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 4, 49.
- Koul, O., Walia, S., & Dhaliwal, G. S. (2008). Essential oils as green pesticides: Potential and constraints. *Biopesticides International*, 4, 63–84.
- Maedeh, M., Hamzeh, I., Hossein, D., Majid, A., & Reza, R. K. (2012). Bioactivity of essential oil from *Zingiber officinale* (Zingiberaceae) against three stored-product insect species. *Journal of Essential Oil Bearing Plants*, 15(1), 122–133.
- Malacrinò, A., Campolo, O., Laudani, F., & Palmeri, V. (2016). Fumigant and repellent activity of limonene enantiomers against *Tribolium confusum* du Val. *Neotropical Entomology*, 45(5), 597–603.
- Mann, S. R., & Kaufman, E. P. (2012). Natural product pesticides: Their development, delivery and use against insect vectors. *Mini-Reviews in Organic Chemistry*, 9(2), 185–202.
- Martynov, V. O., & Brygadyrenko, V. V. (2017). The influence of synthetic food additives and surfactants on the body weight of larvae of *Tenebrio molitor* (Coleoptera, Tenebrionidae). *Biosystems Diversity*, 25(3), 236–242.
- Martynov, V. O., & Brygadyrenko, V. V. (2018). The impact of some inorganic substances on change in body mass of *Tenebrio molitor* (Coleoptera, Tenebrionidae) larvae in a laboratory experiment. *Folia Oecologica*, 45(1), 24–32.
- Oboh, G., Ademosun, A. O., Olumuyiwa, T. A., Olasehinde, T. A., Ademiluyi, A. O., & Adeyemo, A. C. (2017). Insecticidal activity of essential oil from orange peels (*Citrus sinensis*) against *Tribolium confusum*, *Callosobruchus maculatus* and *Sitophilus oryzae* and its inhibitory effects on acetylcholinesterase and Na<sup>+</sup>/K<sup>+</sup>-ATPase activities. *Phytoparasitica*, 45(4), 501–508.
- Opende Koul, O. (2009). Comparing impacts of plant extracts and pure allelochemicals and implications for pest control. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 4, 49.
- Pérez, S. G., Ramos-López, M. A., Zavala-Sánchez, M. A., & Cárdenas-Ortega, N. C. (2010). Activity of essential oils as a biorational alternative to control coleopteran insects in stored grains. *Journal of Medicinal Plants Research*, 4(25), 2827–2835.
- Pimentel, M. A. G., Faroni, L. R. D., Guedes, R. N. C., Sousa, A. H., & Tótolá, M. R. (2009). Phosphine resistance in Brazilian populations of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *Journal of Stored Products Research*, 45(1), 71–74.
- Pushpanathan, T., Jebanesan, A., & Govindarajan, M. (2008). The essential oil of *Zingiber officinale* Linn. (Zingiberaceae) as a mosquito larvicidal and repellent agent against the filarial vector *Culex quinquefasciatus* Say (Diptera: Culicidae). *Parasitology Research*, 102(6), 1289–1291.
- Radulescu, V., Saviuc, C., Chifiriuc, C., Oprea, E., Ilies, D. C., Marutescu, L., & Lazar, V. (2011). Chemical composition and antimicrobial activity of essential oil from shoots spruce (*Picea abies* L.). *Revista De Chimie*, 62(1), 69–74.
- Rotimi, O. A., Chris, O. A., Olusola, O. O., Joshua, R., & Josiah, A. O. (2011). Bioefficacy of extracts of some indigenous Nigerian plants on the developmental stages of mosquito (*Anopheles gambiae*). *Jordan Journal of Biological Sciences*, 4(4), 237–242.
- Russo, S., Cabrera, N., Chludil, H., Yaber-Grass, M., & Leicach, S. (2015). Insecticidal activity of young and mature leaves essential oil of *Eucalyptus globulus* Labill. against *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae). *Chilean Journal of Agricultural Research*, 75(3), 375–379.
- Ryan, M. F., & Byrne, O. (1988). Plant-insect coevolution and inhibition of acetylcholinesterase. *Journal of Chemical Ecology*, 14(10), 1965–1975.
- Saharkhiz, M. J., Motamedi, M., Zomorodian, K., Pakshir, K., Miri, R., & Hemyari, K. (2012). Chemical composition, antifungal and antibiofilm activities of the essential oil of *Mentha piperita* L. *ISRN Pharmaceutics*, 2012, article ID 718645.
- Sandoval-Montenayor, N. E., García, A., Elizondo-Treviño, E., Garza-González, E., Alvarez, L., & del Rayo Camacho-Corona, M. (2012). Chemical composition of hexane extract of *Citrus aurantifolia* and anti-*Mycobacterium tuberculosis* activity of some of its constituents. *Molecules*, 17(9), 11173–11184.
- Scott, I. M., Jensen, H., Scott, J. G., Isman, M. B., Amason, J. T., & Philogène, B. J. R. (2003). Botanical insecticides for controlling agricultural pests: Piperamides and the Colorado potato beetle *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae). *Archives of Insect Biochemistry and Physiology*, 54(4), 212–225.
- Shulman, M. V., Pakhomov, O. Y., & Brygadyrenko, V. V. (2017). Effect of lead and cadmium ions upon the pupariation and morphological changes in *Calliphora vicina* (Diptera, Calliphoridae). *Folia Oecologica*, 44(1), 28–37.



- Singh, G., Kapoor, I. P. S., Singh, P., de Heluani, C. S., de Lampasona, M. P., & Catalan, C. A. N. (2008). Chemistry, antioxidant and antimicrobial investigations on essential oil and oleoresins of *Zingiber officinale*. *Food and Chemical Toxicology*, 46(10), 3295–3302.
- Singh, P., Shukla, R., Prakash, B., Kumar, A., Singh, S., Mishra, P. K., & Dubey, N. K. (2010). Chemical profile, antifungal, antiaflatoxicogenic and antioxidant activity of *Citrus maxima* Burm. and *Citrus sinensis* (L.) Osbeck essential oils and their cyclic monoterpene, DL-limonene. *Food and Chemical Toxicology*, 48(6), 1734–1740.
- Stamopoulos, D. C., Damos, P., & Karagianidou, G. (2007). Bioactivity of five monoterpenoid vapours to *Tribolium confusum* (du Val) (Coleoptera: Tenebrionidae). *Journal of Stored Products Research*, 43(4), 571–577.
- Subasinghe, U., Gamage, M., & Hettiarachchi, D. S. (2013). Essential oil content and composition of Indian sandalwood (*Santalum album*) in Sri Lanka. *Journal of Forestry Research*, 24(1), 127–130.
- Tandorost, R., & Karimpour, Y. (2012). Evaluation of fumigant toxicity of orange peel *Citrus sinensis* (L.) essential oil against three stored product insects in laboratory condition. *Munis Entomology and Zoology*, 7(1), 352–358.
- Tapondjou, A. L., Adler, C., Fontem, D. A., Bouda, H., & Reichmuth, C. (2005). Bioactivities of cymol and essential oils of *Cupressus sempervirens* and *Eucalyptus saligna* against *Sitophilus zeamais* Motschulsky and *Tribolium confusum* du Val. *Journal of Stored Products Research*, 41(1), 91–102.
- Tripathi, A. K., Prajapati, V., Aggarwal, K. K., & Kumar, S. (2001). Toxicity, feeding deterrence, and effect of activity of 1,8-cineole from *Artemisia annua* on progeny production of *Tribolium castaneum* (Coleoptera: Tenebrionidae). *Journal of Economic Entomology*, 94(4), 979–983.
- Tripathi, A. K., Upadhyay, S., Bhuiyan, M., & Bhattacharya, P. R. (2009). A review on prospects of essential oils as biopesticide in insect-pest management. *Journal of Pharmacognosy and Phytotherapy*, 1, 52–63.
- Uysal, B., Sozmen, F., Aktas, O., Oksal, B. S., & Kose, E. O. (2011). Essential oil composition and antibacterial activity of the grapefruit (*Citrus paradisi* L.) peel essential oils obtained by solvent-free microwave extraction: Comparison with hydrodistillation. *International Journal of Food Science and Technology*, 46(7), 1455–1461.
- Wang, J., Zhu, F., Zhou, X. M., Niu, C. Y., & Lei, C. L. (2006). Repellent and fumigant activity of essential oil from *Artemisia vulgaris* to *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal of Stored Products Research*, 42(3), 339–347.
- Wei, A., & Shibamoto, T. (2007). Antioxidant activities and volatile constituents of various essential oils. *Journal of Agricultural and Food Chemistry*, 55(5), 1737–1742.
- Weinzierl, R. (1998). Botanical insecticides, soaps, and oils. In: Rechcigl, J. E., & Rechcigl, N. A. *Biological and biotechnological control of insect pests*. CRC Press LLC, Boca Raton, New York. Pp. 110–130.
- Werdin-González, J. O., Murray, A. P., & Ferrero, A. A. (2008). Bioactividad de aceites esenciales de *Schinus molle* var. *areira* (Anacardiaceae) en ninfas II de *Nezara viridula* (Hemiptera: Pentatomidae). *Boletín de Sanidad Vegetal Plagas*, 34, 367–375.
- Yunis, M. I. (2014). Effect of orange peel (*Citrus sinensis*) (L) extracts and powder on confused flour beetle *Tribolium confusum* (Coleoptera: Tenebrionidae). *Iraqi Journal of Science*, 55(3), 1164–1169.